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16.Summary/Notes *The purpose of this study was to evaluate the spectral channels as well as wavelength regions -- visible, near infrared, middle infrared and thermal infrared - with respect to their estimated probability of correct classification (P_c) in discrimining agricultural cover types. Multispectral scanner data in twelve spectral channels in the wavelength range of 0.4 to 11.7μm acquired in the middle of July for three flightlines were analysed by applying autimatic pattern recognition techniques. The same analysis was performed for the data acquired in the middle of effect of deletion of each spectral channel as well as wach wavelength region on P_c is given. Values of P_c for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels are also given. The overall values of P_c were found to be greater for the data of the middle of August than the data of the middle of July.*

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EVALUATION OF SPECTRAL CHANNELS AND WAVELENGTH REGIONS FOR SEPARABILITY OF AGRICULTURAL COVER TYPES

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ABSTRACT

The purpose of this study was to evaluate the spectral channels as well as wavelength regions -- visible, near infrared, middle infrared and thermal infrared -- with respect to their estimated probability of correct classification (P_c) in discriminating agricultural cover types. Multispectral scanner data in twelve spectral channels in the wavelength range of 0.4 to 11.7µm, acquired in the middle of July for three flightlines were analysed by applying automatic pattern recognition techniques. The same analysis was performed for the data acquired in the middle of August, over the same three flightlines, to investigate the effect of time on the results. The effect of deletion of each spectral channel as well as each wavelength region on P_c is given. Values of P_c for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels are also given. The overall values of P_c were found to be greater for the data of the middle of August than the data of the middle of July.

INTRODUCTION

The purpose of this study was to determine the statistical separability of multispectral measurements from agricultural cover types for evaluation of spectral channels as well as wavelength regions -- visible, near infrared, middle infrared and thermal infrared. The data were analysed in subsets of one to twelve spectral channels, in the wavelength range 0.46 to 11.7µm for selected flightlines of the 1971 Corn Blight Watch Experiment[1]. The agricultural cover types selected were: corn, soybeans, green forage (hay & pasture), and forest. In particular, the objectives of the study were: (1) to study the effect of deletion of each of the twelve spectral channels as well as each of the wavelength regions (visible, near infrared, middle infrared, and thermal infrared), on the statistical separability and corresponding estimated probability of correct classification of the agricultural cover types. (2) To develop a criterion for the evaluation of a combination of wavelength regions based on the estimation of its probability of correct classification of agricultural cover types. Based on this criterion, evaluate all possible combinations of wavelength regions in the subsets of one to twelve spectral channels out of twelve available channels. (3) To investigate the effect of time on these results.

LITERATURE REVIEW

Kumar (1972)[2] has done a thorough review of the general area of 'reflection and emission from plants'. The results of percent correct classification, obtained from the analysis of multispectral scanner (MSS) data by applying pattern recognition techniques, for a flightline divided into four classes (soybeans, corn, water and a mixture of stubble, diverted acres and pasture) were reported in the LARS annual report (1970)[3]. These are summarized as follows:

Performance	Percent Correct Classification Using the Following Wavelength Bands		
	3 Visible (ch.1,2,3) 1 Reflective IR (ch. 4)	3 Visible (ch.1,2,3) 2 Reflective IR (ch. 4,5)	3 Visible (ch.1,2,3) 2 Reflective IR (ch. 4,5) 1 Thermal IR (ch.6)
Training fields (4303 sample points)	86.8	91.9	93.6
Test fields (7135 sample points)	82.8	83.9	86.4

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Where

channel 1 = 0.40 - 0.44 μm, channel 2 = 0.55 - 0.58 μm, channel 3 = 0.66 - 0.72 μm
channel 4 = 0.80 - 1.00 μm, channel 5 = 1.50 - 1.80 μm, channel 6 = 8.00 - 14.0 μm

ch. denotes spectral channel

Coggeshall and Hoffer (1973)[4] have analyzed the multispectral scanner data of a flightline having mostly forest. They have investigated the following in much detail : 1) determination of the optimum number of the 12 available multispectral scanner (MSS) wavelength bands to use for forest cover mapping with automatic data processing (ADP) techniques; 2) determination of the current capability to map basic forest cover types using MSS data and ADP techniques; and 3) determination of the relative utility, to forest cover mapping, of the four spectral regions available in the twelve channel MSS data (i.e., visible, and near, middle and thermal infrared).

They concluded from the tests of classification accuracy of six cover types of interest (deciduous forest, coniferous forest, water, forage, corn and soybeans), that the use of five wavelength bands would fulfill the dual requirements of adequate accuracy and moderate computer time. Their results also indicated that the thermal infrared wavelength region is desirable, but not necessary, for forest cover mapping, and that accurate classification of deciduous and coniferous forest cover can be achieved with the visible plus either the near or middle infrared spectral regions. However, the deletion of the thermal infrared region caused considerable confusion among the agricultural cover types.

Kumar and Silva[5] have investigated the statistical separability of the spectral classes of blighted corn in much detail, data quantity (168 fields having 18804 sample points in ten flightlines) and depth. They found that the greater the difference between the blight levels, the more statistically separable they usually were. In addition, they found that the spectral classes of corn (Healthy and blighted) were most separable in the wavelength range 1.00 to 1.40 μm. Bauer (1974)[1] has discussed the results of 'wavelength band selection', obtained in the Corn Blight Watch Experiment.

Kumar and Silva (1977)[6,7] analysed the multispectral scanner data in the wavelength range 0.4 to 11.7 μm for three flightlines. They found that in the subsets of one to six spectral channels, the combination of wavelength regions (where V, N M and T denote the visible near infrared, middle infrared and thermal infrared wavelength regions, respectively): V, VM, VNM, VNMT, VVNMT, VVNMTT, respectively, were found to be the best choices for getting good overall statistical separability of the agricultural cover types for the data acquired on July 16 as well as August 12. An effort was made to explain these results on the basis of spectral properties of agricultural cover types. The overall statistical separability of the agricultural cover types was found to be greater for the data of August 12 than the data of July 16. The author felt a definate need for doing a further analysis of similar nature to evaluate explicitly each spectral channel, each wavelength region and all possible combinations of wavelength regions for statistical separability and the corresponding probability of correct classification for agricultural cover types.

METHOD OF ANALYSIS

Multispectral scanner data in twelve spectral channels in the wavelength range 0.4 to 11.7 μm, collected with an optical-mechanical scanner at altitudes of 914 to 2133 meters (3000 to 7000 feet) over Western Indiana were analyzed by applying automatic pattern recognition techniques. The wavelength bands of these twelve spectral channels are given in Table I. The data of three selected flightlines, acquired in the middle of July of 1971, were analysed. Each of these three flightlines had fair or good amounts of each of the four agricultural cover types: corn, soybeans, green forage and forest. These three flightlines were selected carefully so that these combined could be considered to be representative of the four agricultural cover types in the Western Indiana.

Black and white photography and gray scale printouts of the spectral channels of the flightlines were used to aid in locating the boundaries of the fields on the LARS (Laboratory for Applications of Remote Sensing, Purdue University) Digital Display*. Sufficient number of

* The LARS Digital Display is a specially designed image display system linked to an IBM 360/ Model 67 using a cathode ray tube as the pictorial medium for gray scale multispectral imagery.

fields of each agricultural cover type were selected carefully so that they could be assumed to be representative of the flightline.

Using the same three flightlines and twelve spectral channels an identical analysis was performed on the data acquired in the middle of August, 1971, to study the effect of time on the statistical separability of agricultural cover types. The multispectral scanner data was acquired on both dates (middle of July and middle of August) between 10.30 a.m. and 12:05 p.m. (local solar time). In addition, these data were of good quality and free from problems like lack of sufficient ground observations, excessive cloud cover, etc. The analysis was done for the data acquired in the middle of July and the middle of August, because corn and soybeans have reached their maximum vegetative growth by these times, and one month of time is sufficient for significant changes to occur in the spectral properties of agricultural cover types. The author wanted to avoid the analysis of data from late September afterwards, because soybeans are harvested in September-October. The author tried to keep all the variables other than time uniform in the two (middle of July and middle of August) sets of data as far as possible. For example, an effort was made to select about the same field boundaries for the two sets of data. A total of more than 600 fields taken from three flightlines were analysed.

Each field was treated as an independent unit and the fields of the same agricultural cover type were put in the same class. The sample points within each field were highly correlated. The LARSYS** statistics algorithm[8] was used to compute the mean vector and covariance matrix (mean and standard deviation) of the classes. In the LARSYS statistics algorithm, cluster algorithm, and feature selection algorithm, each sample point is treated independently in order to make the system convenient and flexible for usage. A key assumption made in these algorithms is that the distributions of the classes are Gaussian. Histograms of the spectral classes defined above were used to check unimodality of the statistical distributions in individual channels. The classes were redefined to eliminate distinct multiple modes. Divergence is defined for any two density functions. In the case of normal variables with unequal covariance matrices, divergence in n spectral channels $C_1, C_2, \ldots C_n$, is given[9] by

$$D(i,j|C_1,C_2,\ldots C_n) = 1/2 \text{ tr } ((\Sigma_i - \Sigma_j)(\Sigma_j^{-1} - \Sigma_i^{-1})) + 1/2 \text{ tr } ((\Sigma_i^{-1} + \Sigma_j^{-1}) (U_i - U_j)(U_i - U_j)^T) \quad (1)$$

where

U and Σ represent the mean vector and covariance matrix respectively; tr A (trace A) is the sum of the diagonal elements of A.

A modified form of the divergence D_T, referred to as "transformed divergence", has a behavior[8,10] more like the probability of correct classification than the divergence, D.

$$D_T = 2 (1 - \exp(-D/8)) \quad (2)$$

Transformed divergence has been used throughout this study.

Although divergence only provides a measure of the distance between two class densities, its use has been extended to the multiclass case by taking the average over all pairs[11]. Let D_{Tij} denote the divergence between classes i and j of a certain flightline, then the average divergence over all class pairs of four classes (each agricultural cover was treated as a separate class) is given by

$$D_{TAVG} = \frac{1}{6} \left[D_{T12} + D_{T13} + D_{T14} + D_{T23} + D_{T24} + D_{T34} \right] \quad (3)$$

$$\text{Let } D_{TMIN} = \text{minimum of } \left\{ D_{T12}, D_{T13}, D_{T14}, D_{T23}, D_{T24}, D_{T34} \right\} \quad (4)$$

Swain[8] (1972) has pointed out that one strategy is to select the subset of features for which

** LARSYS is the earth resources data processing software system of the Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Indiana.

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the average transformed divergence, D_{TAVG} is maximum. While this strategy is certainly reasonable, there is no guarantee that it is optimal. Another strategy[8] is to maximize the minimum divergence, D_{TMIN}, i.e., to select the feature combination which provides the greatest separation between the hardest-to-separate pair of classes.

Let superscripts 1 and 2 with the symbol "D_T" denote the values of transformed divergence for the data acquired in middle of July and middle of August respectively. Let D^1_{TMIN1}, D^1_{TMIN2}, and D^1_{TMIN3} be the values of D_{TMIN} (see eq. (4)) in first, second and third flightline respectively for the data acquired in middle of July.

$$\text{Let } \bar{D}^1_{TAVG} = \frac{1}{3}\left[D^1_{TAVG1} + D^1_{TAVG2} + D^1_{TAVG3}\right] \qquad (5)$$

$$\text{Similarly } \bar{D}^2_{TAVG} = \frac{1}{3}\left[D^2_{TAVG1} + D^2_{TAVG2} + D^2_{TAVG3}\right] \qquad (5A)$$

$$\text{Let } \bar{D}^1_{TMIN} = \text{minimum of } \left[D^1_{TMIN1}, D^1_{TMIN2}, D^1_{TMIN3}\right] \qquad (6)$$

$$\text{Similarly } \bar{D}^2_{TMIN} = \text{minimum of } \left[D^2_{TMIN1}, D^2_{TMIN2}, D^2_{TMIN3}\right] \qquad (6A)$$

The LARSYS feature selection processor was used to find $\bar{D}^1_{TAVG}$ and $\bar{D}^1_{TMIN}$ in all possible combinations of one, two, three, four, five, six, seven, eight, nine, ten, eleven and twelve spectral channels out of the available twelve spectral channels (i.e., the number of all possible combinations of r spectral channels out of n spectral channels = $q = \frac{n!}{r!\,(n-r)!}$).

Throughout this analysis, the combinations of one through twelve spectral channels were ranked so as to get the descending order of $\bar{D}^1_{TAVG}$ and $\bar{D}^2_{TAVG}$ for the data of middle of July and middle of August respectively; for instance, for the data of middle of July, out of all possible combinations of r (r = 1,2 . . . 12) spectral channels out of twelve available channels, the channel combination which had the highest value of $\bar{D}^1_{TAVG}$ was ranked 'first'; the channel combination which had the second highest value of $\bar{D}^1_{TAVG}$ was ranked 'second' etc. In other words

$$\bar{D}^1_{TMAX}\left\{\text{subset of r spectral channels}\right\} = \max\left\{\bar{D}^1_{TAVG}\right\}, \qquad (7)$$

maximized over all possible subsets of r spectral channels out of the available twelve spectral channels for the data of middle of July. From the values of the average transformed divergence, classification accuracy can be reasonably predicted from the results of Swain et al. (1973)[10].

Table I gives the wavelength interval and the corresponding wavelength region of each of the twelve spectral channels. The effect of deletion of each of the twelve spectral channels on $\bar{D}^1_{TMAX}$ (data of middle of July) and $\bar{D}^2_{TMAX}$ (data of middle of August), in terms of the corresponding estimated probability of correct classification (P_c) using the results of Swain et. al.[10] are given in table II. Similarly , Table III gives the effect of deletion of each of the wavelength regions -- visible, near infrared, middle infrared and thermal infrared -- on $\bar{D}^1_{TMAX}$ and $\bar{D}^2_{TMAX}$, in terms of the corresponding estimated probability of correct classification (P_c).

To fulfill one of the main objectives of the study -- evaluation of all possible combinations of wavelength regions in the subsets of one to twelve spectral channels -- the following criterion is proposed:

Each of 12 available channels of the multispectral scanner can be placed in one of the four wavelength regions -- visible, near infrared, middle infrared and thermal infrared, as shown in Table I. Thus, any combination of spectral channels can be called as the corresponding combination of the wavelength regions. For example, channel combination 1, 8, 10 and 12 is called "combination of visible, near infrared, middle infrared and thermal infrared wavelength regions" and is denoted by V N M T. For a given combination of wavelength regions, for example V N M T;

D_{TAVG} and the corresponding value of P_c using the curve of Swain et. al.[10] was calculated for all possible combinations of four spectral channels out of twelve available channels that constitute the combination V N M T. The mean of these values of P_c was calculated for all possible combinations of wavelength regions in the subsets of one to twelve spectral channels, and is shown in Table IV for the data of middle of July as well as middle of August.

RESULTS AND DISCUSSION

The overall separability of green forage from the other agricultural cover types was found to be considerably lower than the corresponding separability of corn, soybeans and forest because the standard deviation of the mean response of green forage was largest among the agricultural cover types. This is because there was much natural variability in the spectral characteristics of hay as well as pasture. The overall separability of forest from other agricultural cover types was found to be considerably higher than the corresponding separability of corn, soybeans and green forage. Green forage and corn were hard to separate, because of considerable overlap in the values of their mean response, due to the large standard deviation of green forage. In addition, it was harder to separate corn from soybeans for the data of middle of July than for the data of middle of August.

Table II shows that deletion of channel 7 reduces P_c by about two percent for the data of middle of July as well as middle of August. The deletion of each of the other channels causes no reduction, or less reduction in the values of P_c, as compared to channel 7. Thus, deletion of any one of the twelve channels does not cause any substantial decrease in the values of P_c, in the subsets of one to eleven spectral channels.

As one would expect, Table III shows that the greatest separability of the agricultural cover types is obtained by using all of the twelve channels. However, an increase in the number of channels, used in a classification algorithm, requires a disproportionate increase in computer time[4]. Without doing a detailed analysis, it seems from Table III that the subset of five channels is likely to fulfill the dual requirements of adequate classification accuracy and moderate computer time. However, this conclusion is very preliminary, because no cost benefit analysis for the data was done.

Table III shows that deletion of each of the wavelength regions causes the following maximum reductions in P_c for the data acquired in the middle of July: visible (3.32, subset of four channels), near infrared (0.38, subset of ten channels), middle infrared (1.10, subset of two channels), thermal infrared (1.02, subset of four channels). The corresponding values of reductions in P_c for the data acquired in the middle of August are: visible (2.07, subset of one channel), near infrared (0.41, subset of ten channels), middle infrared (1.16, subset of two channels), thermal infrared (0.39, subset of eight channels). Thus, it appears that deletion of the visible wavelength region causes more reduction in P_c, as compared to any of the other wavelength regions. The deletion of near infrared wavelength region apparently causes relatively small changes in the values of P_c.

Table II shows that for greatest overall statistical separability of agricultural cover types, channel 7 (0.61 to 0.70μm, red channel) seems to be the best channel. It should be pointed out that the predominant pigments of the plant leaf absorb in the vicinity of 0.44μm, but only chlorophyll[12] absorbs in the red, in the vicinity of 0.64μm. The reason for channel 7 being the best channel may be that there are significant differences in the chlorophyll content of different agricultural cover types, which give rise to differences in their mean response in channel 7, and hence a relatively large value of average transformed divergence between them. An additional reason may be that the red wavelength region is extremely favorable for qualitative and quantitative description of soils[13].

Table IV shows that in the subsets of one to six spectral channels, the combination of wavelength regions V, VM, VMT, VNMT, VVNMT, VVNMMT are found to be the best choices for the data of middle of July. Similarly, for the data acquired in the middle of August: T, NT, VMT or VMT, VNMT, VVNMT or VNMMT, VVNMMT are found to be the best choices. These results are similar to the results obtained by Kumar and Silva[6,7], although a different criterion of evaluation of combinations of wavelength regions was used by them. Obviously, all the seven channels in the visible wavelength region in this multispectral scanner (MSS) are not necessary for getting good separability of the agricultural cover types.

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In the data of middle of July as well as middle of August, V N M T is found to be the best choice in the subset of four channels. It indicates that each wavelength region is valuable in its own way. Because of the presence of water absorption bands in the middle infrared wavelength region, surface geometry of the target and the moisture content of its top layers (of the order of micrometers) determine its reflectance in the middle infrared region. This region is valuable because there are significant differences in the geometry of the surface, and /or moisture content of top layers of the agricultural cover types. The near infrared wavelength region is useful because substantial contrasts between the agricultural covers and soils occur in this region.[1] Thus, this region is especially useful when there are substantial differences in the percentage ground covers of the agricultural cover types. The thermal channel (channel 12) contains information about the radiant temperatures of the targets in the wavelength region 9.3 to 11.7 μm. There are found to be significant differences in the radiant temperatures of the agricultural cover types. The radiant temperature of a plant can be found by doing an energy balance on it and it depends upon factors such as: radiation incident on the plant, plant geometry and size, spectral properties of the plant (including soil), percent ground cover, convection coefficient and transpiration rate of the plant, etc[2]. There are found to be differences in the values of the above variables for different agricultural cover like that give rise to differences in their radiant temperatures. Thus, in the subset of six spectral channels, irrespective of what other five channels were used, adding thermal channel to them usually increased the overall separability of the agricultural cover types.

In conclusion, it should be said that determining which combinations of one, two,..., eleven spectral channels out of twelve available spectral channels give greatest overall statistical separability of the agricultural cover types is a complex problem, because statistical separability in any given combination of spectral channels depends upon many variables, such as quality of data in the spectral channels, quality and quantity of the ground truth available, time of acquiring the data, human decisions (number of fields, field boundaries to be selected, etc.) involved, environmental variables, plant variables, soil variables, etc.[2]. However, determining which combinations of one through six wavelength regions give greatest overall statistical separability of the agricultural cover types is a relatively less complex problem (Table IV). It should be pointed out, although the flightlines analyzed had considerably different characteristics than the flightline analyzed by Coggeshall and Hoffer[4](Introduction), that many of the conclusions presented in this paper are the same as obtained by them. It means that although the analysis was done for three flightlines, the results obtained from this analysis may well be applicable to other flightlines having considerably different characteristics than these three flightlines. The overal statistical separability of the agricultural cover types was found to be greater for the data of middle of August than for the data of middle of July. It should be noted that many of the results obtained from the analysis of the data of middle of July are the same as those obtained from the data of middle of August. This means that, although the analysis was done for the data acquired at two different times, the results obtained from this analysis may well be applicable to the data acquired at some other times of the year.

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TABLE I. WAVELENGTH BANDS OF THE SPECTRAL CHANNELS

Channel Nº	Wavelength Band (Micrometers)	Wavelength Region
1	0.46 - 0.49	visible
2	0.48 - 0.51	visible
3	0.50 - 0.54	visible
4	0.52 - 0.57	visible
5	0.54 - 0.60	visible
6	0.58 - 0.65	visible
7	0.61 - 0.70	visible
8	0.72 - 0.92	near infrared
9	1.00 - 1.40	near infrared
10	1.50 - 1.80	middle infrared
11	2.00 - 2.60	middle infrared
12	9.30 -11.70	thermal infrared

TABLE II. EFFECT OF DELETION OF EACH CHANNEL ON THE PERCENTAGE PROBABILITY OF CORRECT CLASSIFICATION

When using a subset of	Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ (see eq.(7)) when using all the available channels (A)	Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when deleting a channel from the available channels (A)	Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when using all the available channels (B)	Percentage probability of correct classification estimated from $\bar{D}_{TMAX}$ when deleting a channel from the available channels (B)
one channel	84.63	Same (84.63) except deletion of channel (ch.)7 reduced it to 82.64.	86.18	Same (86.18) except deletion of channel (ch.) 7 reduced it to 84.11.
two channels	89.28	Same (89.28) except deletion of ch. 7 and 10. Deletion of ch. 7 and ch.10 reduced it to 88.55 and 89.26 respectively	91.88	Same (91.88) except deletion of ch. 7 and 11. Deletion of ch. 7 and ch.11 reduced it to 91.57 and 91.09 respectively.
three channels	91.58	Same (91.58) except deletion of ch. 7,11 and 12. Deletion of ch.7, ch.11 and ch. 12 reduced it to 90.85, 91.44 and 90.72 respectively	94.64	Same (94.64) except deletion of ch. 3,8 and 11. Deletion of ch.3, ch. 8 and ch.11 reduced it to 94.52, 94.42 and 94.56 respectively.
four channels	93.43	Same (93.43) except deletion of ch.4,7,11 and 12. Deletion of ch.4, ch.7, ch.11 and ch.12 reduced it to 93.13, 93.11, 93.36 and 92.41 respectively.	96.33	Same (96.33) except deletion of ch. 4,8,11 and 12. Deletion of ch.4, ch.8, ch.11 and ch.12 reduced it to 96.28, 96.27, 96.23 and 96.25 respectively.

Note: The effect of deletion of a channel in the subsets of five to twelve channels on the percentage probability of correct classification estimated from $\bar{D}_{TMAX}$, P_c, was rather small except for channel 12, i.e., the maximum reduction in P_c = 0.20 for case (A) and 0.3 for case (B) except for channel 12. The effect of deletion of channel 12 can be found in the Table III. The values of P_c were estimated from the values of $\bar{D}_{TMAX}$ using the curve of Swain and King (1973)[10].
(A) refers to data acquired in the middle of July. (B) refers to the data acquired in the middle of August.

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TABLE III. EFFECT OF DELETION OF EACH WAVELENGTH REGION ON THE PERCENTAGE OF CORRECT CLASSIFICATION

Number of channels in the subset	Values of probability of correct classification estimated from $\bar{D}_{MAX}$ (see eq(7))									
	A_o	A_1	A_2	A_3	A_4	B_o	B_1	B_2	B_3	B_4
one	84.63	82.00	84.63	84.63	84.62	86.18	84.11	86.18	86.18	86.18
two	89.28	87.22	89.28	88.18	89.28	91.88	91.56	91.88	90.72	91.88
three	91.58	88.74	91.58	91.00	90.72	94.64	93.89	94.34	94.42	94.64
four	93.43	90.11	93.43	92.8	92.41	96.33	95.46	96.27	96.08	96.25
five	94.34	92.01	94.34	93.91	93.55	97.22	96.51	97.17	96.79	97.02
six	94.95	np	94.88	94.40	94.23	97.73	np	97.60	97.24	97.43
seven	95.33	np	95.22	94.78	94.66	98.02	np	97.75	97.39	97.73
eight	95.63	np	95.32	95.09	95.05	98.21	np	97.84	97.51	97.82
nine	95.89	np	95.62	95.26	95.31	98.30	np	97.90	97.60	98.02
ten	96.08	np	95.70	95.38	95.48	98.36	np	97.95	97.68	98.11
eleven	96.20	np	np	np	95.58	98.40	np	np	np	98.14
twelve	96.30	np	np	np	np	98.20	np	np	np	np

Note: 'np' denotes that it was not possible to have a combination of m ($m = 1,2,\ldots 12$) spectral channels after deleting the spectral channels in a particular wavelength region. This table gives the values of percentage probability of correct classification (P_c) estimated from the values of $\bar{D}_{MAX}$ (see eq.(7); Swain and King (1973)).[10] A_o, A_1, A_2, A_3 and A_4 denote the values of P_c when using all available channels; deleting spectral channels in the visible, near infrared, middle infrared and thermal infrared wavelength regions respectively for the data acquired in the middle of July. B_o, B_1, B_2, B_3 and B_4 denote corresponding quantities as A_o, A_1, A_2, A_3 and A_4 respectively for the data acquired in the middle of August.

TABLE IV. EVALUATION OF COMBINATIONS OF WAVELENGTH REGIONS

r = 1	(A) P_c	(B) P_c
V	81.8	82.8
N	71.1	80.7
M	81.7	85.0
T	80.7	86.0

r = 2	(A) P_c	(B) P_c
VV	85.0	88.4
VN	85.9	89.1
VM	87.5	90.5
VT	86.9	89.4
NN	77.0	86.1
NM	85.4	89.7
NT	84.4	91.1
MM	85.4	87.6
MT	86.7	90.5

r = 3	(A) P_c	(B) P_c
VVV	86.9	89.4
VVN	87.7	91.8
VVM	89.4	91.8
VVT	88.2	90.9
VNN	87.8	91.9
VNM	89.6	92.4
VNT	89.5	92.5
VMM	89.1	91.1
VMT	90.3	92.5
NNM	87.6	92.4
NNT	86.7	92.4
NMM	87.2	92.0
NMT	87.6	92.2
MMT	88.0	92.0

r = 4	(A) P_c	(B) P_c
VVVV	87.8	90.1
VVVN	89.4	92.4

cont.

VVVM	90.5	92.6
VVVT	90.2	92.0
VVNN	89.7	93.5
VVNM	90.7	95.5
VVNT	90.8	95.5
VVMM	90.3	92.6
VVMT	91.5	95.8
VNNM	90.6	95.3
VNNT	90.5	95.6
VNMM	90.6	95.6
VNMT	91.6	96.1
VNMT	91.2	95.8
NNMM	88.9	94.1
NNMT	89.8	95.3
NNMT	89.6	95.8

r = 5	(A) P_c	(B) P_c
5V	88.8	93.3
(4V)N	91.6	95.8
(4V)M	91.7	95.8
(4V)T	91.7	95.3
VVVNN	91.7	96.0
VVVNM	91.8	96.2
VVVNT	92.0	96.2
VVVMM	91.8	96.0
VVVMT	91.8	96.3
VVNNM	91.6	96.2
VVNNT	91.9	96.2
VVNMM	91.8	96.3
VVNMT	92.2	96.5
VVMMT	92.0	96.4
VNNMM	91.7	96.3
VNNMT	92.0	96.5
VNMMT	92.0	96.4
NNMMT	91.6	96.3

r = 6	(A) P_c	(B) P_c
6V	89.4	93.6
(5V)N	92.2	96.1
(5V)M	92.3	96.2

cont.

(5V)T	92.3	95.8
(4V)NN	92.3	96.3
(4V)NM	92.4	96.5
(4V)NT	92.4	96.4
(4V)MM	92.3	96.4
(4V)MT	92.6	96.5
VVVNM	92.4	96.5
VVVNT	92.5	96.5
VVVMM	92.4	96.6
VVVMT	92.6	96.7
VVVMT	92.6	96.7
VVNNM	92.3	96.6
VVNNT	92.7	96.7
VVNMT	92.8	96.9
VNNMT	92.5	96.8

r = 7	(A) P_c	(B) P_c
7V	89.5	94
(6V)N	92.4	96.6
(6V)M	92.5	96.7
(6V)T	92.4	96.4
(5V)NN	92.5	96.9
(5V)NM	92.6	96.7
(5V)NT	93.5	96.7
(5V)MM	92.5	96.9
(5V)MT	94.7	96.8
(4V)NNM	93.5	96.7
(4V)NNT	93.7	96.7
(4V)NMM	93.5	96.8
(4V)NMT	94.7	96.9
(4V)MMT	94.7	96.8
VVVNNM	93.5	96.8
VVVNNT	94.7	96.8
VVVNMT	94.8	97.1
VVNNMT	94.2	97.1

r = 8	(A) P_c	(B) P_c
(7V)N	92.0	96.3
(7V)M	92.2	96.3
(7V)T	92.2	95.8

cont.

(6V)NN	92.5	96.4
(6V)NM	93.5	96.7
(6V)NT	94.0	96.7
(6V)MM	92.5	96.6
(6V)MT	95.3	96.8
(5V)NNM	94.2	96.8
(5V)NNT	94.7	96.8
(5V)NMM	94.0	96.9
(5V)NMT	95.5	97.1
(5V)MMT	95.5	97.1
(4V)NNMM	93.9	97.1
(4V)NNMT	95.5	97.1
(4V)NMMT	95.6	97.5
VVVNNMT	95.6	97.6

r = 9	(A) P_c	(B) P_c
(7V)NN	92.6	96.6
(7V)NM	93.6	96.8
(7V)NT	94.7	96.8
(7V)MM	93.5	96.7
(7V)MT	95.6	96.9
(6V)NNM	94.7	97.0
(6V)NNT	95.5	97.0
(6V)NMM	95.6	97.1
(6V)NMT	95.8	97.3
(6V)MMT	95.8	97.3
(5V)NNMM	95.5	97.3
(5V)NNMT	95.8	97.5
(5V)NMMT	95.8	97.5
(4V)NNMMT	95.9	97.7

r = 10	(A) P_c	(B) P_c
(7V)NNM	95.5	97.1
(7V)NNT	95.8	97.1
(7V)NMM	95.5	97.5
(7V)NMT	95.9	97.5
(7V)MMT	95.9	97.6
(6V)NNMM	95.8	97.6
(6V)NNMT	96.1	97.6
(6V)NMMT	96.1	97.7
(5V)NNMMT	96.2	98.1

r = 11	(A) P_c	(B) P_c
(7V)NNMM	95.9	97.7
(7V)NNMT	96.1	97.7
(7V)NMMT	96.1	98.0
(6V)NNMMT	96.2	98.1

r = 12	(A) P_c	(B) P_c
(7V)NNMMT	96.3	98.2

Note: r = subset of spectral channels. The column (A) denotes the values of P_c for the data acquired in the middle of July. The column (B) denotes the values of P_c for the data acquired in the middle of August to calculate P_c for a combination of wavelength regions, for example, VNMT: D_{TMAX} was calculated for all possible combinations of spectral channels constituting this combination of wavelength regions. From the mean of these values, the probability of correct classification (P_c) was estimated using the curve of Swain and King[10] (1973). V, N, M and T denote visible, near infrared, middle infrared and thermal infrared wavelength regions respectively.
5V≡VVVVV, 4V≡VVVV etc.

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